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Technical Report

Distribution of Methanol as a Transportation Fuel

by

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Standards Development and Support Branch
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Office of Mobile Source Air Pollution Control
Office of Air, Noise and Radiation
U.S. Environmental Protection Agency

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I. Introduction

This report examines the issues surrounding the distribution of synthetic motor fuels, especially methanol. It is divided into four basic sections. The first is an overview of the existing transportation fuel distribution network. Capacities and historical trends are discussed in this section. The second major division addresses the unique technical factors associated with methanol distribution. Following this, the economics of synfuel distribution are examined. Costs for long-range, local, and retail distribution are presented. The last section draws upon the previous three sections to determine the total distribution capacity needed to support a viable synfuel (either methanol or synthetic gasoline) industry. The total capital costs for such distribution networks are given and compared to the capital cost requirements for synfuel production facilities.

II. Overview of Existing Motor Fuel Distribution System

There are five major means whereby liquid fuels are transported today: pipeline, ocean tanker, inland barge, tank trucks, and rail tank car. These transportation modes have blended into a distribution network according to an evolution which has been underway since Henry Ford popularized the automobile.

The petroleum industry transported about 7.5 million barrels of gasoline per day by these methods in 1977.[1] Table 1 shows the amount of petroleum products delivered by each mode in 1950, 1960, 1970, and 1977. As is apparent, the role played by pipelines has been an expanding one during this time frame as they have not only carried increasing amounts but also the relative percentage transported by pipeline has grown. While the percentage of petroleum products transported by water carriers and rail tankers has significantly declined, it should be noted that with regard to total tonnage, only the rail mode has shown a decline. The amount transported by trucks has increased substantially since 1950 but the percentage has remained fairly constant. Each of these links in the motor fuel distribution system is discussed in more detail below together with a discussion of storage facilities.

A. Pipelines

Pipelines are, in their simplest form, a series of steel pipes welded together, with pumping stations placed at various points along the route to maintain proper flow. They range in diameter from 4 to 58 inches and vary in length from a few miles to a few thousand miles.[1]

Pipelines currently transport over 72 percent of the crude petroleum and roughly 37 percent of refined petroleum products in the United States. Most are common carriers, that is they must carry the product of any company meeting the pipeline's tariffs

Table 1

Petroleum Product Transportation Methods[2]

Year	Pipelines Tons*	Pipelines Percent of Total	Water Carriers Tons*	Water Carriers Percent of Total	Trucks Tons*	Trucks Percent of Total	Railroad Tons*	Railroad Percent of Total	Total Tons*
1950	52.7	12.75	185.2	44.85	130.8	31.66	44.4	10.74	413.1
1960	140.0	21.31	244.2	37.17	242.5	36.93	30.2	4.59	656.9
1970	333.1	31.12	286.4	26.75	425.2	39.72	25.8	2.41	1,070.5
1977**	526.0	36.56	361.7	25.14	524.6	36.46	26.4	1.84	1,438.7

* Tons rounded to nearest million.

** Preliminary.

and regulations as governed by the Interstate Commerce Commission and the Federal Energy Regulatory Commission.[2]

The petroleum products and crude oil pipeline networks and capacities in the U.S. are given in Figures 1 and 2. These figures also show the location of major terminals and refining areas. As can be seen, there is a great concentration of pipelines near highly populated areas and refining centers, especially in the east and midwest. Few, however, are near the western coal fields. Thus, it is more likely that methanol produced in the eastern coal fields will to some degree be able to use existing pipelines than methanol originating in the west. The costs of constructing new pipelines will be addressed in a subsequent section.

Even though the eastern states have a relatively high density of pipelines, there are technical factors which must be considered before concluding that methanol can be transported in them. In addition to material compatibility, discussed later, one such factor of pipeline distribution is batching. This refers to the separation of different products or grades of crude in a single pipeline.[3] Since initial volumes of methanol will be small compared to that of gasoline it is unlikely that entire pipelines would be dedicated solely to methanol transfer. Instead, batching would be used.

Shipments are batched in a continuous sequence with products of similar quality being next to each other. Typically, they are shipped in groups that move from lighter to heavier gravities and then back to lighter in a sequence such as: gasoline-kerosene-fuel oil-kerosene-gasoline. Cycles may be up to 10 days in length, depending on such factors as pipeline capacity, refinery scheduling, and market demand.[3]

If some of the methanol is to be used in blends with gasoline, then it would be desireable to batch it next to gasoline since some mixing of adjacent products occurs.[4] To minimize this interface, or the mixing of different products, batches are sometimes physically separated by devices such as rubber spheres. If the methanol being transported is to be used in a pure form, then this technique would be desireable. Although it has not been attempted, it is believed that pure methanol can be successfully batched through petroleum pipelines.[1] Conoco is currently planning a test program for the summer of 1982 to determine the feasibility of batching methanol in a pipeline.[5]

Ethanol, a similar alcohol, has been successfully batched in a pipeline, however.[4] This was done in January 1981 by William Pipeline Co. of Tulsa, Oaklahoma.[4] They transported 5,000 barrels of ethanol approximately 200 miles through an 8 inch pipeline. Unleaded gasoline was transported on either end of the ethanol in a straight run configuration, i.e., the interface was

Figure 1

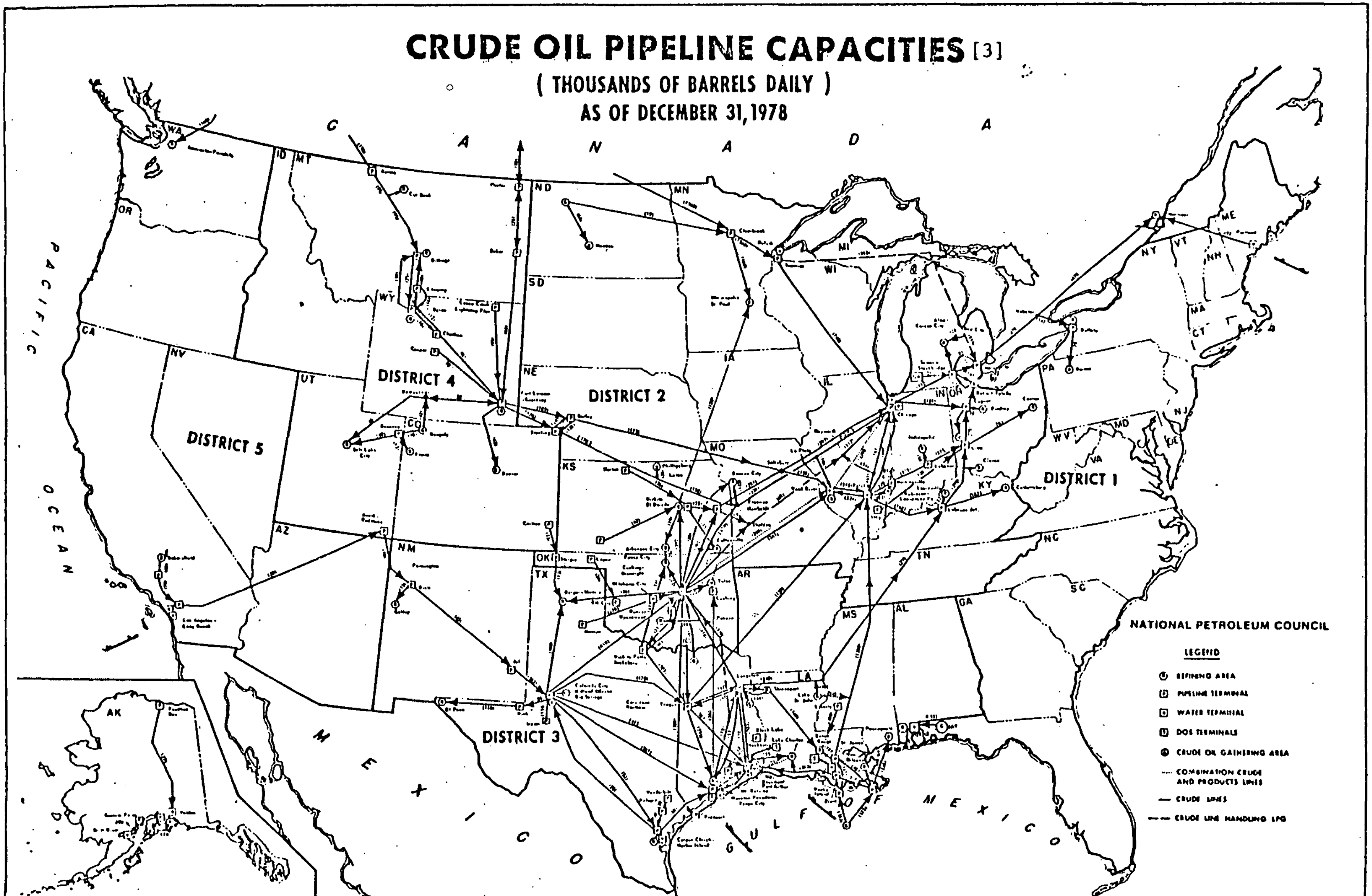
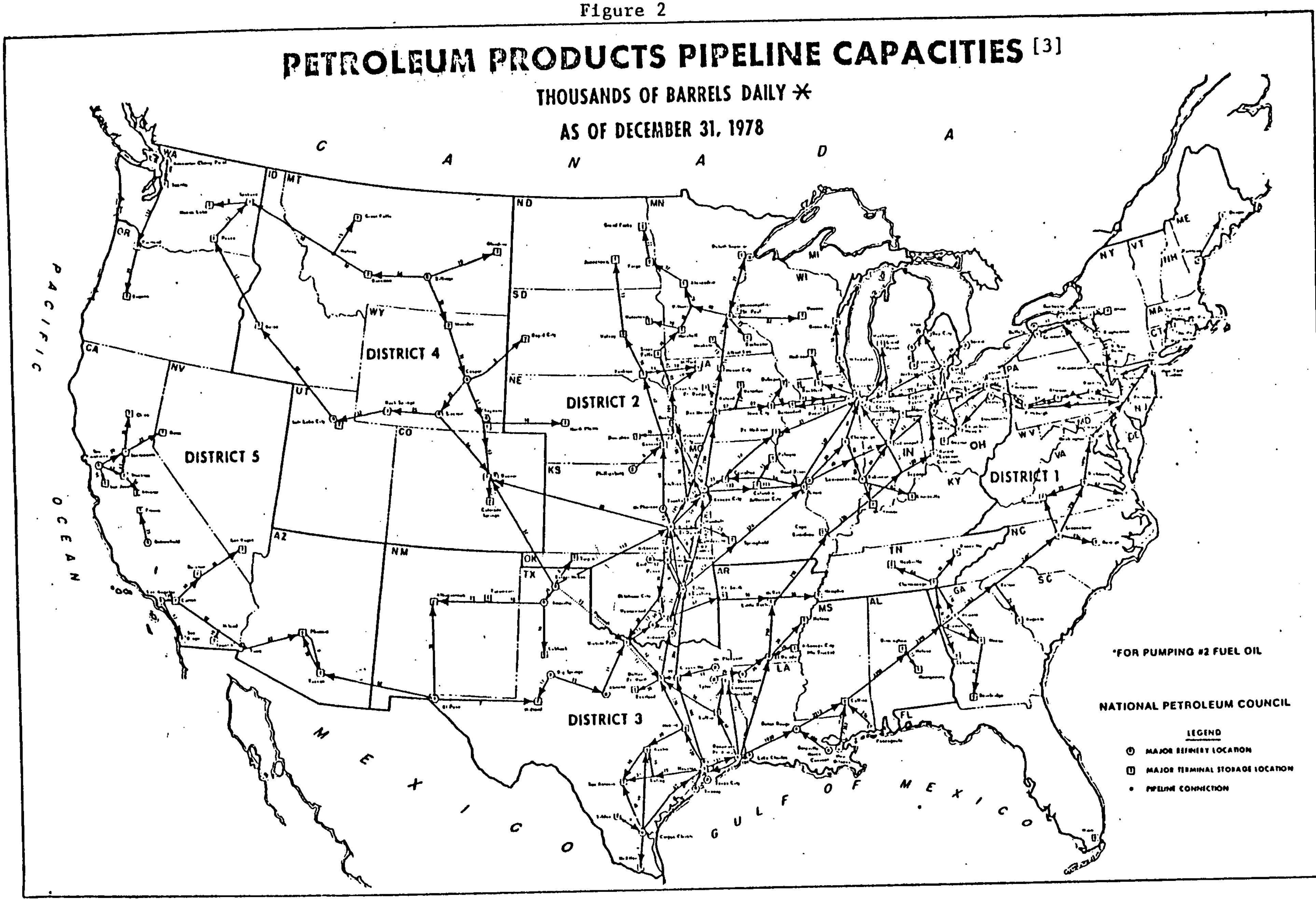

CRUDE OIL PIPELINE CAPACITIES [3]
(THOUSANDS OF BARRELS DAILY)
AS OF DECEMBER 31, 1978
C A N A D A
PACIFIC OCEAN
MEXICO
GULF OF MEXICO
DISTRICT 1
DISTRICT 2
DISTRICT 3
DISTRICT 4
DISTRICT 5
NATIONAL PETROLEUM COUNCIL
LEGEND
REFINING AREA
PIPELINE TERMINAL
WATER TERMINAL
DOE TERMINALS
CRUDE OIL GATHERING AREA
COMBINATION CRUDE AND PRODUCTS LINES
CRUDE LINES
CRUDE LINE HANDLING LPG

Figure 2


PETROLEUM PRODUCTS PIPELINE CAPACITIES [3]
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*FOR PUMPING #2 FUEL OIL
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LEGEND
MAJOR REFINERY LOCATION
MAJOR TERMINAL STORAGE LOCATION
PIPELINE CONNECTION

unprotected by a physical apparatus. As a result, about 200 of the 5,000 barrels mixed with the gasoline during transit. Since the ethanol was ultimately used as a blending agent with gasoline, this mixing was not undesirable.

Special care was exercised in this project to prevent the ingress of water which could lead to phase separation when ethanol (or methanol) is blended with gasoline. These precautions consisted of using only sealed tanks with floating inner roofs (tank designs are discussed in detail in a subsequent section). Similar precautions would also be necessary with methanol if it were to be used in a blending capacity. It should be noted that over the past 10 years, essentially all newly constructed tanks have been the floating roof variety, due to concerns over evaporative hydrocarbon emissions.[4] Even tanks which pre-date this time period are being retrofitted with floating roof tanks. Most of these new and retrofitted tanks are not sealed, however, and would therefore require some modification, as discussed later, to further prevent the ingress of water.

This experience with ethanol indicates that methanol batching should also be feasible. If true, then much of the existing east coast pipeline network could be utilized to distribute methanol, avoiding the necessity of constructing special lines solely to handle methanol.

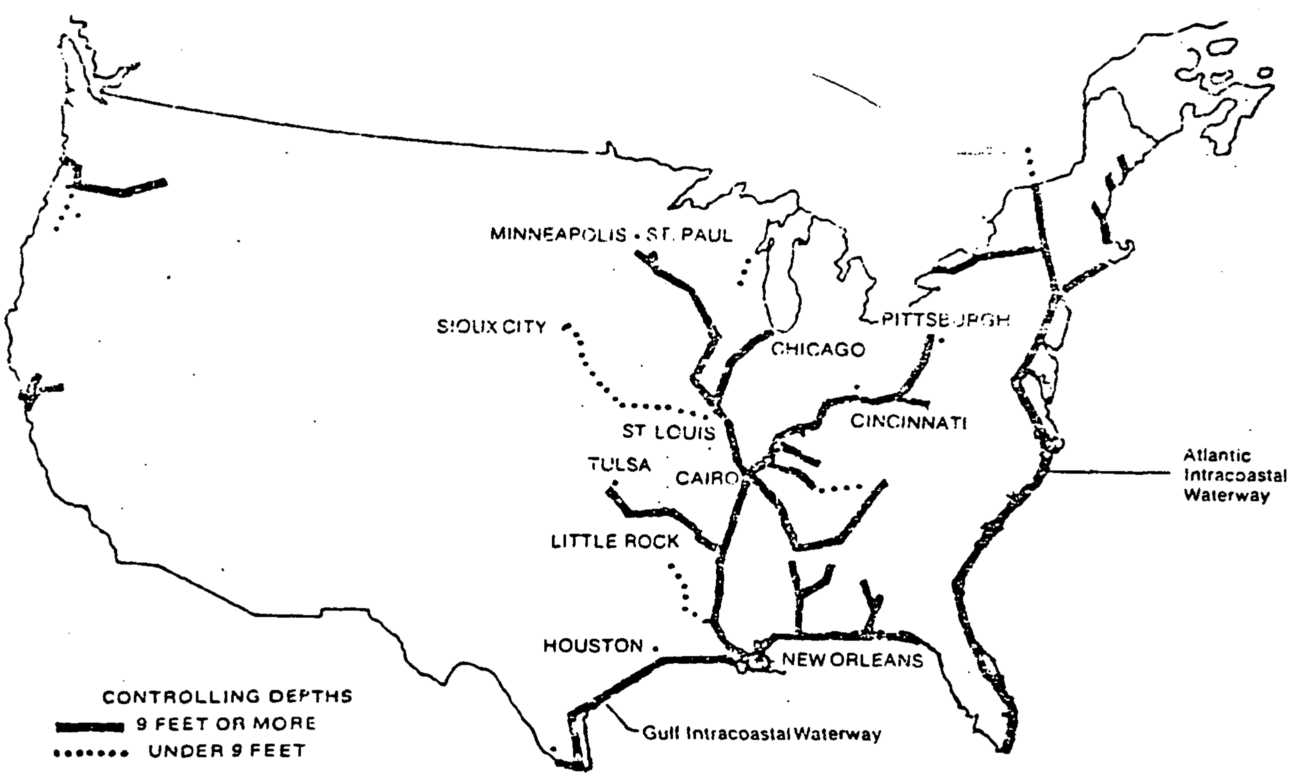
B. Waterborne Transportation

The nation's inland waterways system is illustrated in Figure 3. It consists of approximately 25,000 miles of waterways and includes rivers, intracoastal waterways, canals, channels, and other waterways.[6] In order to be considered navigable, a waterway must facilitate the movement of a sufficient quantity of products to be commercially economic. The width of the waterway, its depth, and the navigability of its bends, locks, and channels are key factors in determining this quantity. Nearly 25 percent of the total inland waterways system is less than 6 feet deep and almost 80 percent is less than 14 feet deep.[6]

As can be seen in Figure 3, navigable waterways, particularly the Ohio and Mississippi Rivers and the Great Lakes, could be used to link methanol production facilities in the eastern U.S. with major population centers in the same region. Western production facilities, in Wyoming and Montana for example, will not be able to rely upon this transportation method. Instead, pipelines or rail tankers (discusssed later in this section) will be needed for long range distribution from the western sites.

The inland waterway industry consists of approximately 1,800 towing companies which serve 87 percent of the nation's major cities.[6] These companies operate over 4300 towboats and tugs with a combined horsepower of approximately 6.1 million. Tank

Figure 3. Commercially Navigable Waterways of the United States. 6/



barges number 3,971 with a total capacity of 71.3 million barrels (refer to Table 2).[6]

Tank barges are either pushed by towboats or pulled by tugboats. Towboats are flat bottomed vessels with multiple rudders for maximum control. They are typically used where large waves are not encountered. In deep water areas and along the coast, the more streamlined tugboats are used to move barges. A towboat may push as many as 20 barges at one time while a tug may pull up to 4 in a simple operation. The larger towboat flotillas have a capacity of up to 200,000 barrels, though in most cases smaller flotillas are dictated by local restrictions.

Another aspect of waterborne transportation is the self-propelled tanker used in coastal and oceanic commerce. These vessels range in capacity from 10,000 to over 1,000,000 barrels.[1] Table 2 shows that as of July 1979, there were 352 of these maritime carriers in the U.S. fleet with a total capacity of over 97 million barrels.

Pipelines generally do not carry heavy products such as residuals due to the relatively high pour points and viscosity of these materials. Thus, domestically, barges and tankers often complement pipelines in moving the heavy petroleum products. Still, gasoline accounts for approximately 50 percent of domestic volume petroleum product movements on inland waterways.[2] Distillate fuel oil accounts for 23 percent and residual fuel oil 12 percent. When foreign tanker imports are included in volume calculations, residual fuel oil is transported in the largest quantities followed by distillate fuel oil, crude oil, and other products.[2] This shift in rank is primarily due to the fact that domestic refineries are optimized to produce gasoline and other high-priced products. Consequently, the U.S. imports large quantities of residual fuel oil.[2]

The large role played by tankers and barges in transporting petroleum products and crude oil has important implications for the future of methanol shipment for several reasons. Of primary importance is simply their availability. Second, these carriers are flexible with regards to the number of major markets they can serve. The Ohio River Valley and Great Lakes for example, are accessible without extensive construction projects which could be needed for pipeline transport. Third, it is significant to note that chemical grade methanol is currently moved by both ship and barge.[1] Thus, the technical expertise gained in this practice should prove beneficial if methanol were used to fuel the nation's vehicles.

C. Truck Tankers

The role of the trucking industry in transporting the nation's petroleum products has long been a vital one. This is

Table 2

Inland Waterways and Maritime Carriers -- Summary, July 1979[6]

	Waterways System	Greater Than 5,000 Barrels Capacity		Less Than 5,000 Barrels Capacity		Total Capacity	
		Number of Units	Total Capacity (barrels)	Number of Units	Total Capacity (barrels)	Number of Units	Total Capacity (barrels)
Self-Propelled Tank Vessels (Tankships)	1. East Coast	152	44,722,553	27	24,190	179	44,746,743
	2. West Coast	55	22,172,689	10	6,391	65	22,179,080
	3. Great Lakes	8	373,270	6	7,988	14	381,258
	4. Alaska	0	0	3	1,244	3	1,244
	5. Hawaii	12	11,566,547	0	0	12	11,566,547
	6. Gulf & Mississippi	74	18,145,074	5	5,169	79	18,150,243
	TOTAL	301	96,980,133	51	44,982	352	97,025,115
Non-Self-Propelled Vessels (Tank Barges)	1. East Coast	335	10,865,387	82	140,591	417	11,005,978
	2. West Coast	91	2,787,437	36	67,363	127	2,854,800
	3. Great Lakes	91	1,425,053	9	13,614	100	1,438,667
	4. Alaska	9	131,433	30	44,523	39	175,956
	5. Hawaii	6	100,567	1	818	7	101,385
	6. Gulf & Mississippi	2,731	54,581,191	550	1,180,519	3,281	55,761,710
	TOTAL	3,263	69,891,068	708	1,447,428	3,971	71,338,496
					TOTAL	4,323	168,363,611

verified by the fact that nearly all oil products and LPG are, at some point, transported by tank truck.[2] Table 1 indicates that the total tons of petroleum products transported by trucks has grown rapidly in recent years.

Tank trucks are primarily used for local distribution and are optimum in the 25 to 50 mile range.[1] Truck tankers are also used in longer hauls to supplement pipeline deliveries in seasonal peak demand periods.[2] New tank trucks are getting lighter and stronger with the increased use of alumimum alloys, stainless steel, and reinforced fiberglass. This lighter weight permits larger payloads, with capacities approaching 11,000 gallons (262 barrels).[2] Because of the many companies that own and operate tank trucks, the short distances involved in most hauls, and the extent of the nation's highway system, truck transport and hence its capacity is difficult to document.

The National Petroleum Council (NPC) has attempted to determine this capacity by conducting a survey of the major trade associations.[7] They estimate that as of December 31, 1978 there were over 50,000 tank vehicles of over 3,500 gallons in capacity in the U.S. The total fleet capacity of these tankers is about 364.4 million gallons (8.7 million barrels). It should be noted that only approximately 80 percent of these tankers were designed to haul liquid products, the remainder being used to transport compressed gases. The NPC reports, however, that all of these vehicles could be used to haul petroleum in an emergency. The degree to which these tankers are compatible with methanol has not as yet been determined. The general subject of materials compatibility will be addressed in a later section.

D. Rail Tank Cars

Several types of tank cars exist with some equipped with heating coils or insulation to facilitate the transportation of heavy fuels and asphalt. Pressurized cars carry LPG while unpressurized, unheated cars are usually relied upon to carry gasoline, aviation fuel, and distillate fuel oils. Capacities of tank cars range up to 50,000 gallons (1190 barrels) or more.[2] As many as 110 tank cars can be connected in a series to form a unit train, making large volume transport possible by rail.[1]

As of June 15, 1979 there were 202,811 tank cars, with a combined capacity of 3.6 billion gallons (85.7 million barrels), in the U.S. fleet.[7] Table 3 gives a breakdown of these tank cars according to their capacity and use. From this table it can be seen that 107,552 tank cars, representing a capacity of 2.2 billion gallons (52.3 million barrels) are suitable for carrying crude oil or petroleum products. Those not suitable are either owned by the railroad to transport diesel fuel for its locomotives or have special design purposes such as acid or caustic soda transport. Also evident from this table is that 77,166 cars

Table 3

Summary of Demographic Breakdown of U.S. Tank Car Fleet [7]
(June 15, 1979)

Age
All Years

	Under 8,500 Gallons	8,500 to 13,499 Gallons	13,500 to 20,499 Gallons	20,500 to 30,499 Gallons	Over 30,500 Gallons	Total Number	Total Capacity
Private Non-Pressure							
Uninsulated	996	2,837	434	10,390	561	15,218	306,131,695
Coiled	3,875	2,674	2,835	14,429	106	23,919	429,313,277
Insulated	387	3,994	130	712	10	5,183	64,048,976
Coiled	1,578	11,689	1,336	18,067	176	32,846	583,110,649
Total	6,836	21,144	4,735	43,598	853	77,166	1,382,604,597
Private Pressure							
Uninsulated	0	627	273	2,060	15,350	18,310	583,595,930
Insulated	599	6,897	92	2,457	2,031	12,076	209,331,725
Total	559	7,524	365	4,517	17,381	30,386	792,927,655
Unsuitable Total	12,755	30,076	32,002	11,060	4,549	90,442	1,327,217,268
RR Owned Total	233	642	1,411	2,518	13	4,817	88,283,117
Grand Total	20,423	59,386	38,513	61,693	22,796	202,811	3,591,032,637

having a capacity of 1.4 billion gallons (33.3 million barrels) are used for nonpressurized transport purposes. It is these cars that would typically be relied upon to carry methanol.

Rail transportation currently constitutes the smallest market share of petroleum product distribution with just under 2 percent (see Table 1). Liquefied petroleum gases and coal gases are moved in the greatest volumes followed by residual fuel oil, asphalts, and lubricating oils.[2]

Despite the diminishing role of railroads in transporting petroleum products, they may be more prominent in methanol transportation. This can be expected since rail lines already connect the coal mines with major markets. Since methanol plants are likely to be sited near the mines, few new tracks would need to be laid. This will be especially important in the west where there is a paucity of navigable waterways, necessary for barge transportation.

E. Storage

1. Primary Distribution System

The system of pipelines, tankers and barges that moves crude oil from producing areas to refining centers, and the similar facilities that move refined petroleum products in bulk to marketing areas, are generally referred to as the primary distribution system.[8] In order to understand the storage aspects of the primary petroleum distribution system, one must be familiar with the concepts of minimum and maximum operating inventories. These are discussed below along with the national storage capacity.

The minimum operating inventory is defined as the inventory required to fill such components as pipelines, tank bottoms, and refinery process equipment in order to maintain normal operations; this volume is considered unavailable for consumption.[8] Shortages and runouts would occur if inventory were to fall below this level. Table 4 indicates that the minimum operating inventory for the U.S. primary distribution system is approximately 720 million barrels with just over 40 percent of that being crude oil.

The maximum operating inventory must also be considered when examining storage capacities. This concept refers to the maximum quantity that could be stored in assigned tankage (plus inventories maintained outside of storage facilities) while still maintaining a workable operating system.[8] In determining the maximum operating inventory a company must allow empty space in tankage to 1) provide room for thermal expansion, 2) receive inventory, and 3) have a margin of error for emergency situations and schedule changes. Exceeding the maximum operating inventory could lead to slowdowns and interruptions in the system.

Table 4

Overview of Primary Distribution System[8]

	U.S. Primary Distribution System Minimum Operating Inventory -- 1978 (Millions of Barrels)
Crude Oil	290
Gasoline	210
Kerosene	35
Distillate Fuel Oil	125
Residual Fuel Oil	60
	720

	U.S. Primary Distribution System Total Shell Capacity of Tankage September 30, 1978 (Millions of Barrels)	Under Construction
Crude Oil	462	12
Gasoline	438	5
Kerosene	90	less than 1
Distillate Fuel Oil	365	3
Residual Fuel Oil	162	1
	1517	21

The tank capacities for crude oil and each of the major refined products are shown in Table 4. The actual measure of stocks lies at any one time somewhere between the minimum operating inventory and the total storage capacity. The National Petroleum Council states that inventory has averaged about 50 percent of tank capacity for the past 30 years (see Figure 4).[8] Since individual tanks alternate between empty and full, the NPC concludes that no significant storage capacity exists for holding emergency supplies.

It is likely that many new primary storage facilities will therefore have to be constructed in order to adequately serve a neat methanol fleet. This is to be expected since methanol's lower energy content compared to gasoline or diesel fuel means that nearly twice the capacity is needed to store the same amount of energy.

2. Secondary Distribution System

The secondary distribution system is comprised of small resellers of petroleum products, such as gasoline service stations or fuel oil dealers.[8] This system along with the consuming sector contains substantial holding capacity. In an analysis of the storage capacity for gasoline and distillate fuel oil in the secondary/consumer network, the National Petroleum Council estimates that capacity exists for at least 500 million barrels, or 60 percent of the primary storage capacity for these products.

Since this network is by definition near marketing areas, there should be no problems with regard to location in using its capacity to distribute methanol.

III. Technical Factors in Methanol Distribution

This section identifies the unique technical problems expected to be encountered when transporting, storing, and dispensing methanol or methanol-containing fuels. Included are discussions on the types of materials found in the distribution system which are known to be incompatible with methanol, the problem of preventing the ingress of water into storage tanks, and ways to decrease the amount of time spent at filling stations (the lower energy content of methanol vs. gasoline or diesel fuel could necessitate more frequent or longer fueling stops).

It should be noted that the estimates below of the extent of the various technical problems of methanol distribution are first order estimates. There is a paucity of data along these lines and more research will be necessary before the net costs associated with a conversion to methanol can be better determined.

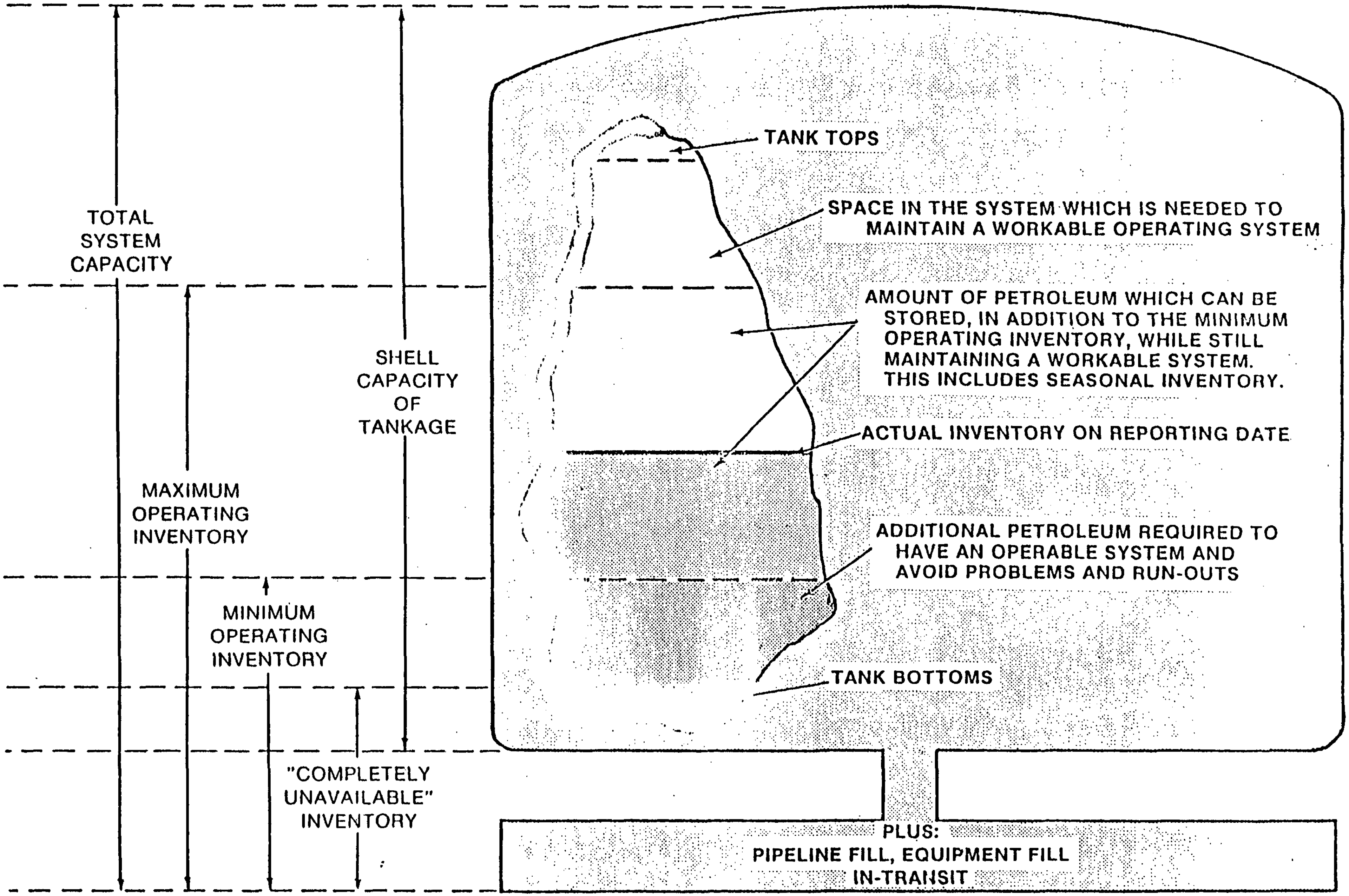


Figure 4. Simplified Diagram of Terms Describing Petroleum Inventories and Storage Capacities. 8/

A. Technical Problems in Transportation

Methanol is highly corrosive to certain materials found in the petroleum product distribution network and has little effect on others. When in contact with ordinary carbon steel such as that found in pipelines, fittings, and valves, it tends to dissolve rust and to slowly corrode the steel.[1] The rate of rust dissolution is fairly rapid but that of steel corrosion is so slow as to warrant no concern. Carbon steel, in fact, is the common construction material for methanol tanks and pipelines.[1]

Because methanol leaches out ordinary pipe dope, it is recommended that either screwed flanges sealed with a teflon thread sealant or welded flanges be used.[1] The normal practice of welding underground piping and coating with asphalt or plastic adhesive tape to prevent corrosion should be followed in the case of newly constructed methanol pipelines.

The pumps used in methanol transfer are made of either carbon steel or bronze lined steel. Either mechanical seals or square asbestos packing is used to seal the pumps and prevent leaks. Since these pumps are essentially the same as those used in handling petroleum products, no change would be necessary to facilitate methanol transfer.[1]

Some plastics are also susceptible to deterioration by methanol. Plastics are often used in the construction of gaskets, O-rings, and packings.[1] Since the chemical industry uses methanol in various processes, they have already faced this type of problem. Neoprene and neoprene-asbestos mixtures were found to be resistant to the debilitating action of methanol.[1] Plastics to be avoided include polyurethane, Buna-N and Viton (common components in some pipelines as well as automobile engines and pumps.)[4,9,10,11]

One final issue relating to material compatibility concerns the batching of methanol in pipelines with other petroleum products.[19] Since methanol is such a strong solvent, it could dissolve the rust inhibiting agents which typically line the insides of pipelines. This potential problem will be addressed in the Conoco research program mentioned earlier.[5]

In addition to the concerns about material compatibility there is another potential problem associated with ordinary valves in such places as transfer lines. This is their susceptibility to blown gaskets and valve packing due to the expansion of methanol when its container is heated by the sun's rays. Relief valves can remedy this situation. Although gasoline also expands when heated, its thermal expansion characteristics are not as pronounced as those for methanol. Thus there are fewer concerns over blown gaskets when shipping gasoline.[12]

B. Technical Problems in Storage

Considerable industrial experience has been accrued in the storage of pure methanol in mild steel tanks with satisfactory results.[1] It has been demonstrated that old steel tanks can be cleaned by removing rust and water with a solvent such as methanol or isobutanol at a low cost.[9,10] These tanks can then be used to store methanol on a permanent basis.

Two related problems in storing methanol are 1) preventing water from entering the tank, which could cause phase separation in methanol-gasoline blends, and 2) preventing breathing losses from the tank as the ambient temperature changes and the level of methanol fluctuates.[1,9,10] The approach taken to resolve these problems depends on which of the two general types of bulk storage tank is being used, floating roof or fixed roof.

Floating roof tanks are commonly used to store gasoline at refineries and large bulk terminals. The floating roof tank has a roof that actually floats on the surface of the liquid. Plastic or rubber collars seal the border between roof and tank wall. This design virtually eliminates breathing losses since the amount of vapor space above the liquid is minimized. As mentioned earlier, this is the reason why floating roof tanks have been in such widespread use over the past 10 years.[4] Tests in Germany and New Zealand indicate that a second seal is needed to prevent water from entering the tank.[9,10] Another, cheaper, solution to the water ingress problem is to simply construct a fixed roof over the tank to keep out rainfall.[1,10]

Fixed roof tanks are typically used to store intermediate and smaller quantities of petroleum products in bulk storage. This tank design is also used for storage of chemical grade methanol. Breathing losses are unavoidable with this type of tank. However, water ingress as vapor or liquid can be prevented by either putting desicators on the air vents or covering the surface of the methanol with a dry gas such as nitrogen or carbon dioxide. Both methods have been used in industrial applications.

Potential storage problems also exist at the retail level. Typically, retail outlets have from one to six storage tanks, each having a 10,000 gallon (238 barrel) capacity. Currently, there are approximately 173,000 service stations nationwide.[1] If each has an average of 4 tanks,[13] then there would be approximately 700,000 tanks in use. These vessels have historically been made of carbon steel which, as pointed out earlier, is a satisfactory material for storing methanol. Since 1965 however, these carbon steel tanks have been systematically replaced by tanks made of a polyester-fiberglass laminate. This material offers superior corrosion resistance to gasoline and its surroundings but is not recommended for methanol storage since it can cause a noticeable increase in the gum content of fuels containing methanol.[10, 13,14] Roughly 10 percent of all retail storage tanks are now made of the polyester-fiberglass laminate and by 2000, 25 percent of all tanks are expected to be of this variety.[13] Replacement of these tanks with carbon steel tanks would be necessary if carbon steel tanks were not available at a station desiring to carry methanol.

C. Potential Dispensing Problems at the Pump

The hoses, nozzles, etc. that are currently being used to dispense gasoline are compatible with methanol.[1] Thus no modifications should be necessary to this type of equipment to prevent corrosion or deterioration of pumping components. However, some modifications may be necessary to increase the pumping rate of methanol because of its lower energy content.

Methanol contains about half the energy as gasoline on an equal volume basis. Since methanol engines are anticipated to have an approximately 20 percent higher fuel efficiency as compared to gasoline engines, roughly 60 percent more methanol on a volumetric basis would be needed to propel a car the same number of miles it would otherwise travel on gasoline.[15] This implies that motorists will not be able to drive as far in methanol vehicles for a given size fuel tank.

A simple solution would be to increase the fuel tank volume by 60 percent. Although this could give a methanol vehicle the same driving range as a gasoline powered vehicle, there are two associated detriments: 1) increasing the tank volume is inconsistent with current trends in downsizing, i.e., it would increase vehicle weight and present possible spacing problems, and 2) since more volume would be pumped, there would be more time spent per fill-up. This could increase crowding at service stations. Even without larger tanks there could be crowding since less energy would be pumped per unit time than is customary. Whether or not this increased crowding would be important is unknown, since the current operating capacity of service stations at peak hours is unknown.

Because of the space and weight constraints it is unlikely that the full 60 increase in tank size would be realized. Some increase, however, is likely so that motorists could have comparable driving ranges to those customary today. Thus the problem of potentially crowded filling stations remains. A possible solution would be to increase the fuel flow rate of the dispenser. This too, however, has potential drawbacks.

These problems are related to a phenomenon known as "spit-back" which results when fuel is fed too fast into the vehicle's tank. Currently, car fill pipes and service station pumps are designed for an approximate 12 gallon per minute (gpm) rate.[16] Some self service stations, however, have nozzles calibrated to 10 gpm to further reduce the likelihood of spitback. This practice is also followed in areas using vapor recovery (such as in California) where flow rates of 8 to 10 gpm are common.

If it were necessary to alleviate this spitback problem the tanks of future vehicles could be constructed to accommodate a higher fueling rate. One possible way to substantially increase this rate would be to use a dual-nozzle delivery system. In this design, the dispenser would have two nozzles instead of the customary single approach. They would be inserted together into separate fill pipes which would follow separate routes to the tank. Thus as much as 24 gallons could be dispensed per minute to the tank, but each fill pipe would only be delivering the usual 12 gpm. This could significantly reduce the amount of time motorists spend actually refueling their vehicles and partially alleviate the crowding problem at service stations.

An additional benefit of the dual-nozzle approach is that it could prevent accidental misfueling with gasoline. The dual methanol nozzle could not fit into the single-holed fill pipes of gasoline tanks. Similarly, if the individual nozzle diameters of the methanol system were slightly smaller than those of the unleaded gasoline dispenser, then gasoline could not be fed into a methanol vehicle's tank. (The nozzles for unleaded gasoline are smaller than those for leaded gasoline for this same reason, i.e., to prevent misfueling.) While this system would require additional equipment on both vehicles and dispensing pumps, the additional costs should be minimal.

D. Summary of Technical Distribution Problems

In conclusion, there are a number of technical factors influencing the distribution of methanol. Of these, material compatibility is the greatest concern. When transporting methanol by pipeline, it may leach out ordinary pipe dope, for instance. Screwed flanges sealed with teflon or welded flanges could alleviate this problem. There appears to be no compatibility problem with the carbon steel of the pipeline itself or the pumps used to facilitate transfer. Similarly, the steel construction of barges and rail and truck tankers should present no problem for methanol transfer. Some plastics, however, such as polyurethane, Buna-N, and Viton found in gaskets, O-rings and packings in some pipelines are not compatible with methanol and would have to be replaced. Noeprene and neoprene-asbestos mixtures are adequate replacement materials.

In bulk storage, floating roof tanks are needed to minimize both water ingress (especially when methanol is used as a blending agent) and evaporative emissions (whether or not it is a blending agent). As mentioned earlier, this type tank has become more and more popular over the last 10 years due to concerns over reducing evaporative emissions. Tests indicate, however, that a second sealing may need to be added to provide adequate water protection.

Storage at the retail level could present the most problems if the current trend of relacing carbon steel tanks with ones constructed of polyester-fiberglass laminate continues. This latter material causes an increase in gum content of methanol containing fuels. By 2000, at the current rate of replacement, approximately 25 percent of all tanks would be the polyester-fiberglass type.

There appear to be few compatibility problems at the dispensing pumps. However, because of methanol's lower volumetric energy content, there could be increased crowding at filling stations. This is expected since 1) more frequent stops would be made by motorists if their fuel tanks are kept at the current size for gasoline vehicles; and 2) more volume per fill-up would be needed if on board tank size is increased to make driving range more compatible with that of gasoline vehicles. It is unknown at this time whether or not this increase in pumping time would adversely affect service stations since their current operating conditions are unknown. However, an increase in the fuel delivery rate, possibly via a dual-nozzle pump, could alleviate this problem if it arose.

IV. Economics of Synfuel Distribution

In a draft study performed by DHR, Inc. for the Department of Energy to investigate methanol use options, the cost of both methanol and gasoline distribution from two hypothetical synfuel production facilities to regional distribution centers was considered.[1] One plant was located in the coal fields of southern Illinois and the other in northeastern Wyoming. Each plant has a 100,000 barrel per day capacity (methanol). The logistics and costs of fuel delivery from these plants to specified sites is discussed below. Following this discussion, typical local distribution and retailing costs are given and conclusions reached about the total cost of distributing methanol and synthetic gasoline.

It should be noted that a conservative approach in terms of methanol distribution costs was followed in this report. That is, in each aspect of distribution, long-range, short-range, and retail, assumptions were made which would tend to increase the cost of methanol distribution relative to that for synthetic gasoline. In most instances, for example, future methanol vehicles were assumed to have the same energy efficiency as their gasoline counterparts, although it is generally believed they will be roughly 20 percent more efficient. This approach was followed in order to help assure that the costs of distributing methanol were not underestimated, since some costs of converting to methanol are inevitably overlooked at this early stage.

A. Overview of Illinois and Wyoming Methanol Plants

The southern Illinois plant would be located near several major markets including St. Louis, Chicago, Toledo, Indianapolis, Kansas City, Cincinnati, and Louisville. To simplify the study, it was assumed that the entire product from this plant would be distributed solely to St. Louis and Chicago. Both of these markets are more than large enough to consume such quantities of methanol.

Both St. Louis and Chicago are major oil refining areas located by the Mississippi River and Lake Michigan, respectively. Each area has major storage terminal facilities and is connected by a network of common carrier product pipelines (refer to Figure 1) which could be used to distribute methanol. Systems for transporting the methanol from the production plants to these areas, however, would need to be devised. A pipeline from the Illinois methanol plant to St. Louis would be approximately 100 miles long, while one to Chicago would be roughly 300 miles in length. A pipeline construction company contacted as part of the above mentioned study reports that for a marketing split of roughly one-third to St. Louis and two-thirds to Chicago, the necessary pipeline diameters would be 10 inches and 12 inches, respectively.

The Wyoming plant near Gillette is located further than the Illinois plant from major markets, the closest ones being Denver, Minneapolis, Omaha and Kansas City. As with St. Louis and Chicago, these markets also have major terminal storage facilities for petroleum products and are connected to other markets by pipeline. Minneapolis and Kansas City have access to inland waterways. Only Denver, however, has a pipeline which comes near Gillette. A pipeline connecting the Wyoming plant with the primary markets would be approximately 1,000 miles long and 10 to 24 inches in diameter.

B. Specific Costs in Transporting Methanol

As discussed earlier, the major means of transporting fuels long distances within the U.S. are pipeline, barge, and rail tank car. Of these, all but barge transportation are likely components in the distribution network surrounding the two design plants; each is too far from inland waterways to make barges feasible.[1] Table 5 shows the average transportation cost for methanol for the two remaining modes, pipeline and rail tank car. These are discussed below. Costs for distributing synthetic gasoline will be addressed in a subsequent section.

1. Pipelines

Of the two means of transporting methanol listed in Table 5, pipelines are the cheaper. As can be seen from this table, the

Table 5

Average Transportation Costs for Methanol
(1981 dollars per million Btu)[1,17]

Railroad Tank Car Transportation Costs (Unit Trains)

Distance, Miles	Cost
100	.28
200	.35
400	.58
600	.78
800	1.01
1000	1.28

Pipeline Transportation Costs

Distance, Miles	Bbl/Day Pipe Dia., Inch	50,000 10	100,000 14	200,000 20
50		.07	.049	.025
100		.12	.082	.033
200		.19	.12	.07
500		.41	.28	.19
800		.58	.41	.26
1000		.72	.48	.33
1200		.85	.59	.39

operating cost decreases significantly as the volume transported increases. These costs are similar on a volumetric basis to those incurred in transporting gasoline via pipeline since the physical properties of methanol and gasoline are similar.

The overall installed capital costs for pipelines in an average terrain outside of metropolitan areas is $11,000 per diameter inch-mile (1981 dollars).[1] For metropolitan areas, the capital costs rise to $33,000 per diameter inch-mile.[1] These costs consist of right-of-way, pipe costs and installation and pumping station equipment. Typically, capital charges of depreciation, interest, taxes, and insurance account for 75 percent of the pipeline transportation cost with operating and maintenance costs accounting for the remainder.

2. Rail

As mentioned earlier, there are two modes of railroad tank car transportation: small volume transport with a few cars in a mixed freight train or large volume transport as a unit train with roughly 100 cars. Unit trains usually only apply to a fixed route, but are less costly than individual tank cars in a mixed train. The average cost for railroad transportation by unit train is given in Table 5. From this table it can be seen that railroad tank car transportation costs are 2.7-3.4 times higher than those for a 14 inch pipeline carrying 100,000 barrels per day of methanol. Operating and maintenance costs account for approximately 85 percent of the rail costs while capital charges account for the remaining 15 percent.

3. Storage Costs

The bulk terminal storage and blending costs would be approximately $0.13-0.17 per million Btu (mBtu) of methanol.[1] This includes operating and maintenance and capital costs. The capital costs for bulk storage facilities constructed of standard mild steel are given in Table 6.

C. Distribution Costs from Production Sites to Bulk Terminals

Distribution costs for transporting pure methanol and gasoline from both the Southern Illinois and Wyoming sites discussed earlier to markets (bulk terminals) are presented in the following sections. In both cases, the assumption was made that methanol would be carried by pipeline to markets and then stored in bulk terminals and blended or marketed as needed. In addition, distribution costs from another study will be discussed and compared to that of the DHR report.

Table 6

Bulk Storage Capital Costs
(1981 Dollars)[1,17]

Storage Tank Size, Bbl	Cost
125,000	$ 313,000
250,000	474,000
500,000	719,000
1,000,000	1,090,000

1. Southern Illinois Plant

Table 7 shows the distribution costs to a bulk terminal from this plant for the two fuels as determined by DHR. The distribution costs are $0.31 per mBtu for synthetic gasoline and $0.56 per mBtu for methanol. Note that these costs include terminaling costs. Terminaling costs are the same for both methanol and gasoline since they include such factors as labor, grounds keeping and to a smaller degree electricity which are essentially the same for both products.[18]

The gasoline costs reported by DHR, however, appear to be based on the assumption that the capital cost of a gasoline pipeline would be roughly one-half that of a methanol pipeline transporting the same amount of energy. (Recall that the energy density of methanol is about half that of gasoline.) This is overly simplistic since the volumetric flow of a pipeline varies with the cross-sectional area and, as indicated by DHR themselves, pipeline capital cost is proportional to the radius and not the area or volumetric capacity.

To estimate a revised cost of transporting gasoline by pipeline, it will be assumed that the DHR statement that 75 percent of such costs are due to capital charges, and the remainder operating and maintenance, is correct. As determined by DHR, pipeline capital costs are assumed to be proportional to pipeline diameter. Operating and maintenance costs for gasoline pipelines are estimated to be 25 percent less than a comparable methanol pipeline transporting the same amount of energy.[18] This last estimation is based on the assumption that two-thirds of operation and maintenance costs in a gasoline pipeline are due to such factors as labor and maintenance and one-third due to pumping costs. For a methanol pipeline the labor and maintenance costs would be very nearly the same but the pumping costs would be roughly twice as high since twice the volume is being transported.[18] Following this procedure, synthetic gasoline would cost approximately $0.37 per mBtu to distribute to a bulk terminal from the southern Illinois plant.

The capital costs of the methanol pipeline (as determined by DHR) and gasoline pipelines (as determined by the above procedure) are also given in Table 7. Together, the methanol pipelines cost roughly $65 million. To transport the energy equivalent in gasoline, the 100 mile pipeline would be approximately 7 inches in diameter and the 300 mile pipeline would have a diameter of 8.5 inches. Together, the gasoline pipelines would cost $46 million.

2. Wyoming Plant

In this example, DHR assumed that one 14 inch diameter pipeline 1000 miles long would carry all the methanol to either Minneapolis, Chicago, or Kansas City. The capital costs for this

Table 7

Distribution Costs to and Including a Bulk Terminal
For a Southern Illinois Methanol Plant, $/mBtu
(1981 Dollars)[1,17]

	Pure Methanol	Gasoline	
		DHR	Revised
Pipeline, 100 miles to St. Louis, 33%; 300 miles to Chicago, 67%	.31	.16	.22
Bulk terminal operating cost*	.15	.15	.15
Added storage in bulk terminal	.10	___	___
	.56	.31	.37
Pipeline Capital Cost: (millions of dollars)			
100 mile, 10 inch diameter	15.3		
100 mile, 7 inch diameter		10.8	
300 mile, 12 inch diameter	49.7		
300 mile, 85 inch diameter		35.2	

* No interest charges are made for the stored fuel.

pipeline would be $165 million (see Table 8).[1] Following the procedures outlined in the previous section, a pipeline to carry the same amount of energy in the form of synthetic gasoline would be 10 inches in diameter and cost roughly $118 million.

The costs associated with distributing methanol and synthetic gasoline from the Wyoming plant to a bulk terminal are given in Table 8. DHR estimated these distribution costs to a bulk terminal to be $0.40 per mBtu for gasoline and $0.73 per mBtu for methanol. As was the case with the southern Illinois scenario, however, DHR apparently assumed the cost to transport gasoline by pipeline would be one-half that of methanol. Using the aforementioned capital cost for a 10 inch pipeline for gasoline and the same 75/25 split of capital costs and operating and maintenance costs discussed earlier, synthetic gasoline would cost $0.50 per mBtu to distrbute.

3. <u>Average Cost of Fuel Delivery to Bulk Terminal (Long Range)</u>

If one assumes that half of the nation's synfuel plants are located in the west and half in the east, then an average nationwide distribution cost from production facility to bulk terminal can be obtained from the previous two sections. By averaging the values given in Tables 7 and 8, one obtains a typical methanol distribution cost of $0.65 per mBtu and a revised cost of $0.44 per mBtu for synthetic gasoline.

In a less detailed report than the DHR study described above, ICF, Inc. also examined the costs associated with methanol/synthetic gasoline distribution.[19] Both short- (268 miles) and long- (1,039 miles) range pipeline scenarios were examined in that study also. There, the average cost of distribution from production facility to bulk terminal was estimated to be $0.44 per mBtu for methanol and $0.22 per mBtu for synthetic gasoline. These costs, however, did not consider terminaling costs; the DHR study did. When these costs are subtracted from the DHR estimates given above, average distribution costs from plant to bulk terminal are estimated to be $0.40 per mBtu for methanol and $0.29 per mBtu for synthetic gasoline (revised). As can be seen, the two reports are in close agreement, especially for methanol where the DHR estimate is $0.04 per mBtu less. The gasoline estimates are further apart and the ICF projection is the lower of the two. This is due to the fact that ICF made the same simplistic assumptions concerning the relative costs of methanol and synthetic gasoline transport discussed earlier. That is, gasoline would cost one-half as much to distribute via pipeline as methanol. Using the original DHR estimate based on this assumption for comparisons, an average distribution cost for synthetic gasoline would be $0.21 per mBtu. This is very close to the ICF value of $0.22 per mBtu.

Table 8

Distribution Costs to and Including a Bulk Terminal
For a Wyoming Methanol Plant, $/mBtu
(1981 dollars)[1,17]

	Pure Methanol	Gasoline DHR	Gasoline Revised
Pipeline, 1000 miles to Minneapolis, Chicago, or Kansas City	.48	.26	.35
Bulk terminal operating cost*	.15	.15	.15
Added Storage in bulk terminal	.10	___	___
	.73	.40	.50
Pipeline Capital Cost: (millions of dollars)			
1000 mile, 14 inch diameter	165		
1000 mile, 10 inch diameter		118	

* No interest charges are made for the stored fuel.

D. Distribution Costs from Bulk Terminal to Retailers (Local Distribution)

Local distribution is primarily done by tanker truck. Since trucks would be making periodic trips, as opposed to the fixed pipeline carrying fuel, it is likely that the costs per unit volume would remain fairly constant. Some economies of scale could probably be realized from a switch to methanol, but overall more trips will have to be made since trucks cannot increase in size by the necessary amounts due to state weight limitations.

This approach was followed in Table 9, which gives the costs of transporting synthetic gasoline and methanol by tank truck for distances from 5 to 75 miles. These costs are based on trucks with 9,000 gallon capacities with one stop delivery and an empty backhaul. Capital costs account for roughly 40 percent of total costs while operating and maintenance accounts for the remaining 60 percent. Tank trucks cost $76,000-82,000 each with $49,000-55,000 for the tractor and $27,000 for a trailer having vapor recovery equipment.[1] For the purposes of this study, a typical distance of 50 miles will be used. Thus, local methanol distribution would cost $0.28 per mBtu while synthetic gasoline would cost $0.14 per mBtu to transport this distance.

E. Retailer Costs

The costs of retailing fuel are more like those of long-range distribution than local distribution. That is, the costs of retailing are primarily fixed costs, such as land or rent. Unlike the case with long-range distribution, however, large capital investments should not be required. Instead of installing more storage tanks to facilitate the sale of larger volumes of methanol, it would be more likely that the service station would merely receive more frequent deliveries from the bulk terminals. Instead of filling their methanol tanks once a month, for example, the retailer would fill these tanks every two weeks. Such a procedure would avoid the capital costs associated with installing new storage tanks, unless of course his existing tanks are not compatible with methanol. Retailing also differs from both long-range and local distribution in that the critical marketing factor is fuel energy used and not volume. The following example should clarify this point.

First, let it be assumed that gasoline and methanol cost the same per unit energy (e.g., gasoline is $2.00 a gallon and methanol is $1.00 per gallon). Also, let it be assumed that both gasoline and methanol engines have the same fuel efficiencies, so that a person with a methanol-fueled auto buys twice the volume of fuel as a person with a gasoline-fueled car. With methanol, each retailer would sell twice the volume of fuel as compared to gasoline, but the same amount of energy, and would obtain the same amount of revenue. His operating costs would change very little,

Table 9

Tank Truck Distribution Costs[1,17]
(1981 Dollars)

Distance (Miles)	Cost, $ per mBtu	
	Methanol	Gasoline
5	.13	.07
25	.21	.11
50	.28	.14
75	.37	.19

since his fixed costs dominate and actual pumping costs are negligible.

The above scenario is very reasonable, except that it is likely that methanol engines will be as much as 20 percent more fuel efficient than gasoline engines and less total energy will be required. If this were the case, then each vehicle would require less fuel (in terms of energy) per fill-up or fill-up less often. In either case, retailers would see a reduction in sales, but costs would remain at or very near prior levels. If all stations remained in business, then the total cost of fuel retailing would remain constant under this scenario, as it did under the prior scenario. Since the total amount of energy distributed will be 20 percent less, the cost for retailing methanol per mBtu will be 25 percent higher. However, experience with the current gasoline retailing situation might say that the current drop in demand for gasoline is forcing some retailers out of business, and reducing the overall cost of retailing. In the extreme, then, one might expect that a 20 percent drop in fuel (energy) usage would result in the need for 20 percent less retailers and reduce overall retailing costs by 20 percent. In this case, the cost for retailing methanol per mBtu would be the same as gasoline since both the amount of energy and the cost of retailing would decrease by 20 percent. Since it is impossible to determine which of these situations would actually occur, both will be used to bracket the possibilities.

Typical retailer mark-ups are estimated to be in the range of \$0.05-0.18 per gallon of gasoline.[20] However, since the lower mark-ups are usually associated with the high-volume stations, the average mark-up per gallon of gasoline sold in the U.S. should be nearer to the lower limit, about \$0.09 per gallon, or \$0.76 per mBtu. For methanol, the cost would lie between this value and 25 percent more since the total amount of energy distributed would be 20 percent less due to the expected higher efficiency of methanol engines. Thus, the cost of retailing methanol would be \$0.76-0.95 per mBtu.

In deriving these retail costs, no attempt was made to account for any additional costs the retailer would bear when methanol is first introduced. For example, he will have to make some monetary allowance for the initial small volume of customers. The retailers in some instances will also incur costs associated with installing new tanks if the existing ones are incompatible or unavailable due to large demands for the specific fuels they contain. (This topic is addressed in Section V.) The aforementioned retailing costs should therefore be considered as long-term costs, after the methanol market stabilizes.

As mentioned earlier, in the cases of long-range and local methanol distribution costs, it was assumed that methanol vehicles would have the same fuel efficiency as their gasoline counterparts. Thus, the volume of methanol needed was twice that for synthetic gasoline. Although this approach appears inconsistent with that followed to determine retail costs, each procedure is conservative with respect to the estimation of methanol distribution costs. That is, in all instances the assumptions were made which would tend to increase the cost of distributing methanol relative to gasoline. This was done to help assure that the costs of distributing methanol were not underestimated, since some of the costs of conversion are inevitably overlooked.

F. Total Distribution Costs

The total cost of distributing methanol and synthetic gasoline can now be determined by combining the costs presented in the last three sections. Methanol would cost $1.69-1.88 per mBtu to distribute; gasoline would cost $1.34 per mBtu. Gasoline has a significant advantage over methanol in terms of percentage (21 to 29 percent), but the absolute difference is only $0.35-0.54 per mBtu.

In order to understand the implications of these higher methanol distribution costs, it is useful to know what fraction of the total fuel cost is due to distribution. In Table 10 the plant-gate,[21] distribution, and at-the-pump costs for methanol and synthetic gasoline are given. As can be seen, distribution accounts for 13-22 percent of methanol's price at the pump and 8-15 percent for gasoline. Thus, it is clear that the dominating factor in determining the retail price of each fuel is production costs.

V. Distribution Capacity Needed to Support a Synfuel Industry

In the first two sections of this report the existing petroleum fuel distribution system and technical factors affecting methanol distribution were discussed. A key question to be answered when considering the viability of a given synfuel is "how much distribution capacity is needed to support it?" This section expands upon the discussions in the first two sections in an attempt to answer this question. Also, this section will discuss the total capital cost of implementing this capacity based on the findings of the previous section.

A. Future Fuel Needs

First, it will be necessary to know approximately how much methanol or synthetic gasoline must be distributed to fuel the nation's automotive fleet. Table 11 shows the expected consumption of gasoline and diesel fuel for selected future years as projected by Data Resources, Inc.[22] To simplify this discussion, it will be assumed that synfuels will be used to meet 20 percent of the nation's transportation fuel needs by the year 2000.

Table 10

Synthetic Fuel Costs*[21]
($ per mBtu)

	Methanol	Synthetic Gasoline
Plantgate Costs	5.90-12.42	7.35-15.29
Distribution Costs	1.69-1.88	1.34
Cost at Pump	7.59-14.30	8.69-16.63

* The range of plantgate costs for each fuel reflect differences due to capital charge rates of 11.5 and 30 percent. Bituminous coal was used as a feedstock to each. The methanol price range is from the Texaco process (low) and the Koppers process (high). That for synthetic gasoline was based on the Mobil MTG process.

Table 11

Future Motor Gasoline Demand
(Billions of Gallons)[22]

	1985	1990	1995	2000
Motor Gasoline	89.6	81.1	78.2	78.4
Regular	23.2	9.7	9.2	8.7
Unleaded	66.4	71.4	69.0	69.7
Diesel	20.5	29.8	36.7	43.8
	110.1	110.8	114.9	122.2

The 122.2 billion gallon total for gasoline and diesel fuel in 2000 has the same energy content as 267.4 billion gallons of methanol.[14] Thus, if methanol were chosen to meet 20 percent of these needs, approximately 53.5 billion gallons of that fuel would suffice. Similarly, if synthetic gasoline is relied upon for 20 percent of the nation's transportation needs in 2000, then roughly 27 billion gallons of it would be necessary. The total volume of transportation fuel in the year 2000 under the 20 percent methanol scenario is roughly 151.3 billion gallons, while that for the synthetic gasoline option is 122.2 billion gallons.

B. Long-Range Capacity

In order to produce 53.5 billion gallons of methanol annually, 35 methanol plants would be needed, each producing 100,000 barrels per day. Without knowing where each of these plants would be located it is impossible to know the exact nature of the associated distribution network. To simplify the discussion here and to represent an upper limit of needed capacity it will be assumed that new pipelines will be constructed to facilitate all long-range distribution.

In the previous section it was determined that for western markets, a 14-inch pipeline would be sufficient to transport 100,000 barrels of methanol per day 1,000 miles to major markets. Similarly for eastern markets, two pipelines, 10 and 12 inches in diameter, stretching 100 and 300 miles, respectively, could also facilitate 100,000 barrels per day to major markets. Assuming that 17 of the necessary 35 methanol plants are located in the west and 18 in the east, then there would be a need for 17,000 miles of 14 inch pipelines, 5,400 miles having a 12 inch diameter and 1,800 miles with a 10 inch diameter.

The capital costs for these individual new pipelines were given earlier and can be found in Tables 7 and 8. Using these values, the aggregate cost to the nation for new methanol pipelines for the above methanol scenario would be roughly $4.0 billion.

Following a similar approach for the synthetic gasoline option, 17,000 miles of 10 inch diameter pipeline would be needed to connect western production facilities with major markets. For the 18 production facilities in the east, 5,400 miles of 8.5 inch diameter pipeline and 1,800 miles of 7 inch pipeline would be needed. Using the individual capital costs given in Table 7 and 8, the aggregate cost to the nation for the new synthetic gasoline pipelines would be approximately $2.8 billion. Thus, pipelines to facilitate the methanol option would cost roughly $1.2 billion more nationwide than that needed for the synthetic gasoline route.

C. Bulk Terminal Capacity

Typical gasoline bulk terminals are large enough to facilitate an approximate 10 day supply from the refinery.[13] If this rule of thumb is also applied to methanol, then the average bulk terminal would need to hold 1 million gallons for each methanol plant that sends its total production to it. Since, however, a given volume of methanol is in effect replacing half that volume of gasoline, the storage capacity that previously went to the gasoline should be available for methanol. Thus only 500,000 gallons of capacity would have to be added to each terminal for each 1 million gallons of methanol it would store. From Table 6 it can be seen that a storage tank of this size would cost $719 thousand. The total costs to the nation to construct enough methanol storage tanks at bulk terminals to store the production of 3.5 billion barrels per day would be roughly $25 million. Note that this cost does not include the purchase of land on which to locate the additional tanks. This was not included since the degree such land would be needed and the associated costs are unknown. These costs, however, should be minimal compared to that for tank purchases.

For the synthetic gasoline option, it is likely that existing gasoline terminals would also be accessible to synthetic gasoline. Thus no additional tanks at bulk terminals would be needed.

D. Tank Truck Capacity

As noted earlier, the National Petroleum Council estimates that as of December 1978 there were approximately 40,000 tank vehicles hauling liquid products.[7] The total capacity of these trucks was approximately 291.5 million gallons.[7] The average size truck in such a fleet would have a capacity of nearly 7,300 gallons. For that same year, Data Resources reports a total of 122.8 billion gallons of motor fuel were consumed.[22] Thus, each tank truck has a yearly haul of approximately 3 million gallons, or approximately 420 hauls per truck per year.

Since a total of 151.3 billion gallons of fuel (methanol, gasoline and diesel) are needed under the 20 percent methanol scenario, there would be 28.5 billion gallons more fuel consumed in 2000 than in 1978. If the number of hauls per truck per year remains constant, and assuming the same ratio of tank truck to nationwide capacity, the same individual tanker capacity as that sited above, and no spare capacity in either the 1978 or 2000 systems, then an additional 9,300 tank trucks would be needed. Tank trucks this size cost roughly $78,000 each.[1] Thus the total cost of 9,300 tankers would be approximately $725 million. Since nearly the same volume of fuel was consumed in 1978 as is projected for 2000 under the synthetic gasoline option, no additional capacity would be needed in 2000 for gasoline over the 1978 level.

If, however, the trucks dedicated to methanol transfer make twice as many hauls per year to retail outlets as their gasoline counterparts then no additional trucks would be needed over that necessary for gasoline transportation. This is a likely scenario given the significant cost of tanker trucks.[23] Although this approach would not require an initial capital investment for methanol delivery trucks, the fact that they would be operating twice as many miles per year as the gasoline trucks indicates they will need replacing twice as often. Thus, in the long term, the $725 million additional dollars for methanol tankers will have to be spent, but the impact would be spread out over a number of years.

E. Retail Capacity

If, as depicted above, approximately the same volume of fuel was consumed in 1978 as is projected for 2000 under the synthetic gasoline option, then no additional retail capacity would be needed for gasoline in 2000 over 1978 levels. Given the likely scenario whereby retail methanol tanks would be filled twice as often as gasoline tanks, there would similarly be no need for additional storage tanks for methanol. Those constructed of fiberglass laminate will, however, need to be replaced by carbon steel tanks due to their incompatibility with methanol. Since, as mentioned earlier, fiberglass tanks will only comprise roughly 25 percent of all retail tanks in 2000, and since methanol will only comprise a fraction of service station storage needs, the degree of this substitution is likely to be minimal.

F. Cost Comparisons Between Synfuel Options

The total costs of implementing distribution networks for the two synfuel options can now be approximated by combining the individual costs for each distribution component. This has been compiled in Table 12. As can be seen the distribution network for a scenario which yields 20 percent of the nation's transportation fuel needs in 2000 by methanol would cost roughly $4.75 billion. A similar network whereby the same fraction of fuel was supplied by synthetic gasoline would cost $2.8 billion, or $1.95 billion less than the methanol option.

In order to put these findings into perspective, one must also consider the differences in the production facility capital costs associated with each scenario. It has been estimated that a methanol plant of the size depicted in this study would cost at least $680 million less than a similar facility which yields gasoline.[21] The relative capital costs here are approximately $1.99 billion for a methanol plant and $2.67 billion for the synthetic gasoline facility.

Thus, to produce enough methanol to meet 20 percent of the fuel demand in 2000 would require an investment of approximately $69.7 billion. If the synthetic gasoline route were chosen, the

Table 12

Capital Costs of Synfuel Distribution in 2000
(Billions of 1981 Dollars)

	Methanol	Synthetic Gasoline
Pipelines	4.0	2.8
Bulk Terminal	0.025	0.0
Tank Trucks	0.725	0.0
Retail Capacity	0.0	0.0
Total	4.75	2.8

total capital costs for the requisite production facilities would be $93.5 billion. As can be seen, the capital costs for distribution are dwarfed by production capital costs which are 15 to 33 times as great.

VI. Conclusions

It has been noted that the petroleum product distribution network is very complex and extensive. Since there are few pipelines and navigable waterways near the western coal fields, it is likely that new pipelines will be needed to support synfuel production in this region. Railroads are typically located near these fields and thus could be relied upon in the initial stages of synfuel implementation. Their high costs relative to pipelines, however, precludes their long-term use. In the eastern half of the U.S., there are many pipelines and navigable waterways which could support synfuel distribution to some degree. Here also, railroads which already connect coal fields with major markets could be relied upon in the early stages.

The extent to which the existing distribution system can be used to support a synthetic fuels industry is impossible to determine accurately due to the lack of information concerning the exact location of future synfuel plants and unanswered questions regarding the compatibility of these new fuels, especially methanol, with materials in the existing network.

Material compatibility problems of methanol which have been identified include: 1) its leaching out of ordinary pipe dope in pipelines, 2) the dissolution of rust inhibitors from pipeline inner walls during batching, 3) the deterioration of certain plastics and rubber compounds, and 4) the tendency of methanol fuels to gum when stored in polyester-fiberglass laminate tanks. None of these problems appear to be significant at this time. Research has been initiated by major oil companies to examine these and related issues in more detail.

The cost of distributing methanol from plantgate to customers at a retail outlet is approximately $1.69-1.88 per million Btu. Similarly, synthetic gasoline would cost roughly $1.34 per million Btu to distribute. These costs are responsible for 13 to 22 percent of methanol's price at the pump and 8 to 15 percent for synthetic gasoline using production cost estimates developed elsewhere.

In order for methanol to meet 20 percent of the nation's transportation fuel needs in the year 2000, approximately $4.75 billion would be required to increase current capacity in the motor fuel distribution network. If synthetic gasoline were relied upon to meet this same requirement, then $2.8 billion would be needed. Thus, choosing methanol would necessitate the spending of $1.95 billion over that required for synthetic gasoline to facilitate distribution.

These capital costs are quite small, however, compared to those necessary to construct the requisite production facilities. A single methanol production facility yielding 100,000 barrels per day costs, for example, approximately $680 million less to construct than a comparable synthetic gasoline plant ($1.99 billion versus $2.67 billion). Thus, the construction costs associated with building enough methanol plants to meet 20 percent of domestic needs in 2000 would be approximately $69.7 billion. Synthetic gasoline plants necessary for this amount of fuel would cost a total of roughly $93.5 billion. The methanol route would therefore be $23.8 billion less expensive in terms of plant costs.

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